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ELECTRIC CURRENT
AS AN
AGENT FOR PERSONNEL INCAPACITATION

Prepared by:

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ELECTRIC CURRENT AS AN AGENT FOR PERSONNEL INCAPACITATION

PROBLEM

To evaluate, especially from the physiologic point of view, electric current as an agent for personnel incapacitation.

DISCUSSION

I. Potential Applications for Incapacitation

Electric current possesses a number of possible advantages when compared to other proposed agents for personnel incapacitation. Controlled electric shock offers, not necessarily simultaneously, the following possibilities:

Broad spectrum of incapacitation: annoyance, fear, intimidation, pain, muscle spasm, minor burns, paralysis, suffocation, unconsciousness, severe burns, death.

Relative predictability of physiologic effect: reliable relationship between dose and responses.

Controllability: of dose and on/off times.

Directivity: with respect to person to be incapacitated and body part(s) to be affected.

Effectiveness on a wide range of subjects: regardless of determination or level of consciousness.

Rapidity of incapacitation: onset of action within a second.

Rapidity of recovery: only a few seconds for the milder effects.

Safety: for both the operator and the subject,* if desired.

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* Throughout this report, subjects are assumed to be healthy, adult humans in the 45 to 90 kilogram weight range.

Covertness: quiet and unobtrusive, can be camouflaged.

Aside from technical details of the delivery system, the only broad limitations to use of electric current as an incapacitation agent have to do with the number of subjects and the duration of incapacitation. It is difficult to conceive of realistic circumstances that would permit a safe and uniform dose to be administered to a number of subjects at one time, although current would be as effective for the entire group as it is for an individual. In this report, current is considered as an incapacitating agent for individuals only. Electric current can be quite safe for periods of incapacitation of a few seconds only; hazards become much greater if current is used to maintain incapacitation for a minute or longer, unless special techniques and precautions are used.

Within these limitations, current could be used as an incapacitating agent under virtually any circumstances. Power can be supplied from permanent supply lines, temporary generators and lines, or portable supplies (including pocket-sized battery packs in some cases). Delivery systems might be permanent installations, temporary traps, hand-held instruments or long-range projectile devices. Automatic controls would suffice for systems designed for brief incapacitations, but systems maintaining incapacitation for more than a few seconds should be controlled by an operator who has some training in the methods of safeguarding the health of the subject.

II. Physical Variables of Electric Current

The performance and suitability of electric shock for personnel incapacitation may be affected by several variables which characterize the incapacitating current. The more important electrical parameters are voltage, current, power (or energy) and frequency. For familiarity, these and other terms used in this study are briefly defined in Table I.

TABLE I

DEFINITION OF BASIC ELECTRICITY TERMS

Characteristic	Brief Definition	Symbol	Unit
Voltage	Electrical pressure or the electromotive force tending to move electrons, potential	E	volt
Current	Volume of electron flow	I	ampere
Direct Current	Current that does not vary in direction or magnitude with time	DC	ampere
Alternating Current	Current that has continuous sinusoidal variation in direction and magnitude with time	AC	ampere
Frequency	Rate of alteration of an AC current	f	Hertz (cycles/sec)
Resistance	Opposition to the flow of direct or alternating current	R	ohm
Impedance	Opposition to the flow of alternating current	Z	ohm
Pulsed Current	Current that flows intermittantly, but repeatedly	--	--
Energy	Capacity to do work	--	joule
Power	Rate of delivery of energy, the product of voltage and current	P	watt

Electric currents are most often supplied from batteries (direct current) or from rotating generators (either alternating or direct current). The current is usually carried from one locale to another by low resistance conductors, such as non-ferrous metals, or by ionized liquids or gases, and is prevented from leaving the desired path by high resistance insulators. The application of current or voltage to basic electrical devices, including resistors, coils, and capacitors, permits a wide range of functions to be performed by electricity. These basic electrical devices coupled with more complicated devices, such as vacuum tubes and transistors, form the working components of all electrical and electronic systems which generate, transmit, store, amplify, modulate or otherwise control electric current.

Purposeful control of the variables of electricity can be accomplished through the use of these basic devices. For example, a coil or inductor will tend to conduct direct current and low frequency alternating current, while impeding high frequency alternating current. Similarly, a capacitor or condenser acts as a conductor for high frequency alternating current, but impedes direct current and low frequency alternating current.

The spectrum of physical and physiological effects produced by the variations of voltage, current and frequency is probably familiar to many readers: the tingle of a mild electric shock of low amperage, the appearance of a high voltage arc discharge, the accidental burn from 110 volt, 60-Hertz "house current" or the painful shock from the high voltage of an automobile ignition system.

In terms of incapacitation and biological effects on living systems, current - not voltage - is the most important variable of electricity. The frequency of the current may also be a factor in determining the deleterious effects of electric current, especially with regard to the sensitivity of the human heart.

III. Physiological Considerations*

A. Effects of Electrical Current on Humans

With the exception of inconsequential effects such as the feeling of hair-standing-on-end, high voltages without current flow have no known effect on human well-being or performance. Polarity of a direct current or brief discharge makes no apparent difference with regard to the incapacitating effects of flowing current.

As it relates to the incapacitation problem, electric current has only three significant effects on human tissues:

1. Depolarization of nerve and muscle tissue, causing the "firing" of nerve or brain cells and contraction of muscle fibers. Depolarization causes the subjective tingle, involuntary muscular contractions and several other side-effects of an electric shock.

2. Change in sensitivity of certain irritable tissues, such as increased heart irritability and sensitivity to fibrillation. † Fibrillation is an uncoordinated "bag-of-worms" contractile activity of the heart, and is a major threat to life which may ensue when moderate electrical currents pass through the heart. Death can follow because a fibrillating heart cannot pump blood.

3. Heating, to the point of coagulation and burning if current flow is large enough or concentrated in a small area.

All three of the above effects could contribute to the pain of a severe shock, although a large part may be pain due to muscle spasm.

* Unless otherwise attributed, the material presented in this section is derived from Reference 1, which also provides a bibliography of the basic publications on the physiologic effects of electric current.

† In this report, fibrillation means ventricular fibrillation.

Detailed effects can be predicted if the amperage, route through the body, duration of current flow and frequency of the power supply are known. Deliberate execution in an electric chair is an extreme example in which approximately 10 amperes of 50 to 60 Hertz current are passed from head to both feet for longer than a minute. Such a lethal current causes immediate unconsciousness; immediate and continuous "tetanic" contraction of all major muscles including the heart, thereby arresting respiration and all useful heart activity, and severe heating effects most pronounced where the special electrodes make contact with the skin. The colloquial phrase "frying in the chair" seems apt.

A less drastic but equally dramatic use of electric current is in electroconvulsive therapy or "shock treatment" for mental illness. In this case, 50 to 60 hertz currents on the order of 1 ampere are passed from one side of the head to the other for one-half second or less.[2] The patient immediately loses consciousness and has a generalized convulsion that appears to last longer than the duration of current application. The patient usually regains consciousness within a few minutes and may be physically able to walk promptly. There is likely to be residual muscular soreness and a confusional state may persist for any period of time from seconds to days. The patient retains permanent amnesia for the time of the shock and usually makes no serious objection to repeat treatments. Therapy personnel take great care to make large-area, low-resistance electrical contact on both sides of the head to prevent current burns on the patient's scalp. It must be emphasized that current flow, and hence all <u>direct</u> effect, of electroconvulsive therapy, is confined to the head. The depolarizing action of the current on the brain causes convulsive stimuli to flow out to the muscles through the normal channels of the nervous system; there is no significant current flow through the trunk or extremities although they move violently. Only organs in the path of the current flow can be affected directly. This is why there is no risk of direct electrical interference with heart action during properly conducted electro-convulsive therapy.

Currents passing through the torso can cause spastic paralysis of the respiratory, back and abdominal muscles. Continuous paralysis of the respiratory muscles for several minutes can lead to suffocation regardless of other consequences. The most immediate and potentially lethal threat posed by a current passing through the chest, however, is electrical interference with heart activity. Table II outlines the hazards of currents applied externally to the chest for several seconds.

Inspection of Table II reveals several key points. For a given current level in the 0 to 3,000 milliampere range, alternating current has greater physiologic effect and is more hazardous than direct current. Fibrillation of the heart is rarely caused by direct current regardless of amperage. Ventricular fibrillation is almost always fatal unless given special treatment* within minutes, but hearts that have been completely paralyzed for short periods usually resume normal activity spontaneously after the current stops. This difference accounts for the apparent paradox in the dose-response relationships shown for alternating currents: other factors being equal, a current greater than 3 amperes is less likely to be immediately fatal than currents in the 80 milliampere to 3 ampere range. It must be emphasized that the approximations indicated by Table II are valid only for current applied externally across the chest and for the indicated durations. The voltage required to produce a given current, of course, is highly dependent on the nature of the electrodes, skin resistance, and other factors.

The fibrillation threshold rises for current durations shorter than one second, at least for non-repetitive pulses of current. Figure 1 indicates an approximate "worst case" threshold for fibrillation hazard in terms of the current-time factor for brief exposures to any type of current, including 60 Hz AC and capacitor discharges. For shocks lasting less than one second, the threshold shown by Figure 1 is for constant energy pulses of 1.6 joule

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* The standard method of "closed" defibrillation is to apply about 300 joules of electrical energy in 0.2 seconds or less through large electrodes held firmly on the skin of the anterior chest.[1] One joule is one watt-second.

TABLE II

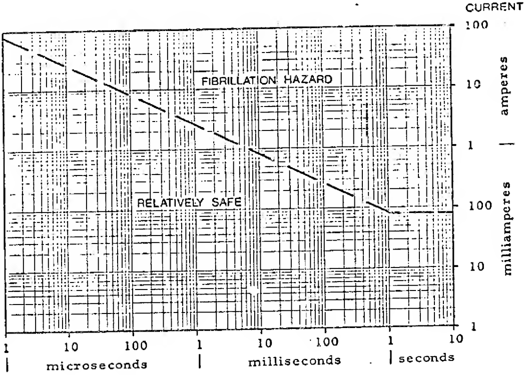
SENSATION AND EFFECTS ON HEART AND RESPIRATORY MUSCLES OF CURRENTS * LASTING 1 TO 30 SECONDS [1] (THRESHOLDS APPROXIMATE)

Current (ma)	Sensation AC†	Sensation DC	Heart AC†	Heart DC	Respiratory Muscles AC†	Respiratory Muscles DC
0-1	none	none	none	none	none	none
1-5	tingle	none	none	none	none	none
5-25	pain	tingle	none	none	slight contraction	none
25-80	pain	pain	none ‡	none	paralysis	slight contraction
80-300	pain	pain	fibrillation	none	paralysis	paralysis
300-3,000	pain	pain	fibrillation	paralysis	paralysis	paralysis
over 3,000	pain, burns	pain, burns	paralysis	paralysis	paralysis	paralysis

* For currents applied externally to the chest; currents smaller than 0.1 milliampere can cause fibrillation if applied directly to the heart.[3]

† 10-1,000 Hertz

‡ Exposure longer than 30 seconds may cause fibrillation



DURATION OF CURRENT
(Continuous, Non-Repetitive Flow)

Figure 1. Approximate Threshold of Heart Fibrillation Hazard for Single, Brief Current Surges (AC or DC)[1]

each. Several authorities suggest that hazard threshold might well be at energy levels an order of magnitude higher than that shown; thus the threshold shown by Figure 1 may be quite conservative.[1]

Currents of sufficient magnitude will cause painful involuntary contraction of muscles as the currents pass through an extremity. The motion made by the extremity as the muscles contract will depend upon: (1) the muscle groups stimulated, and (2) the relative strengths of contraction of the various muscle groups. A person "thrown" or "knocked down" by electric shock has been moved by his own muscle contractions rather than any direct propulsive effect of the current. Relatively weak movements caused by small currents can be overcome by voluntary muscle control, especially in large powerful people. A "no-let-go" current threshold can be determined by measuring progressively larger currents flowing through a person's arm from an electrode grasped in his hand, up to the current at which he can no longer voluntarily release the electrode with the current flowing. The no-let-go threshold for adults is in the 6 to 30 milliampere range for 60 Hz AC. Current values will be similar for other AC frequencies in the 10 to 1,000 Hz range, but DC currents would have to be about five times as large for similar effect.[1]

B. The Human Body as an Electrical Conductor

From the standpoint of electrical shock, the normal human body can be considered as a bony framework encased in a protein gel with some lipids, all of which is permeated with an aqueous salt solution and encased in a waterproof skin. The electrical resistance of organs generally varies inversely with water content. Tissues such as blood and muscle display resistances in the order of 1,000 ohms per cubic centimeter while dense bone, fat and nervous tissues have resistances several times higher. Whole body resistance, exclusive of skin, is on the order of 200-1,000 ohms. The trunk has a lower resistance than the extremities with their smaller cross section and high proportion of bone. Current inside the body appears to spread in a

fairly uniform manner through the available volume between the point of entrance and the point of exit rather than being noticeably concentrated along any special low-resistance path.

The skin usually presents the major resistive barrier to electric current flow. Most of the skin resistance is in the epidermis, the dry, horny outer layer without blood vessels. Thickness of the epidermis, and hence the resistance of the skin, may vary widely between different parts of the body. Thin skin behind the knee or in the axilla may offer less than a thousand ohms resistance, especially if moist. At the other extreme, a thick, dry callous may offer resistance approaching a million ohms. Skin that is relatively moist, such as on the palms, soles or axillae, will be more conductive than drier skin of the same thickness elsewhere on the body.[1] During sound sleep, all skin resistance rises greatly.[4]

C. Skin Resistance

The major factors in electrode-to-body resistance through the skin are:[1]

1. Thickness and intrinsic moisture of the skin, as noted above. Range: about 1,000 - 1,000,000 ohms (dry contact).

2. "Wet" or dry contact. Presence or absence of an electrolyte solution providing a conductive pathway between electrode and skin. "Wet" contact can be proveded by special preparations such as electrode paste or fluids such as sweat, blood, saline solution or even tapwater. Conversion from a dry contact to a "wet" one usually drops the resistance one or two orders of magnitude.

3. Intact or damaged skin. Any thinning, scratching or penetration of the epidermis can drastically reduce skin resistance. In addition to any reduction due to a wet contact, painless, gentle sandpapering of the skin can also reduce the resistance one or two orders of magnitude. Even a tiny penetrating burn, such as that caused by a small area of contact with high voltage, will cause a near-instantaneous drop in skin resistance to a

few hundred ohms or less.

4. Area of contact. Other factors being equal, resistance is inversely proportional to the area of contact. A large area of uniform dry contact is difficult to achieve in practice. Significant and predictable reduction in resistance by large area contact is ordinarily achieved only with wet contact such as immersion of a body part or wet clothing.

5. Pressure of contact. Increased pressure on a dry contact with intact skin can reduce resistance, but the effect is usually not pronounced enough to cause dry electrode-to-skin resistances lower than 10,000 ohms until the contact pressure exceeds 10 kilograms per square centimeter.

6. Frequency of the electric power. Skin impedence, or total tendency to obstruct the flow of electric current, is inversely proportional to increases in the frequency of the applied electric power. The relationship is not sufficient to lower the effective skin impedance two orders of magnitude until the power supply frequency approaches 100 kHz. This report is not concerned with such radio frequency currents because "skin effect" keeps most of the current on the body surface where it is ineffective as an incapacitating agent.

7. Skin covering. Dry hair and most dry clothing can increase the electrode-to-body resistance by millions of ohms.

D. Burns and Other Thermal Injuries

The heating effects of electric current are dependent upon the amount of electrical energy being dissipated per unit time in a given volume of conductor. About four joules of electrical energy must be dissipated in a gram of water in order to heat the water one degree centigrade. In general, the temperature rise of tissue being heated by electric current varies:

1) directly with the square of the current
2) directly with the resistance of the tissue
3) directly with the time of current flow
4) inversely with the effective volume or cross-section of the conductor

Consideration of these facts leads to the conclusion that the highest temperature rises in most cases of electrical shock will occur in the skin at one or both points of electrical contact with the body. For significant current flows, skin burns of some degree will remain a hazard unless special precautions are taken to avoid high skin resistance and small effective cross-sections of electrical contact with the skin.

Conversely, the large effective cross-section and low resistance of the body beneath the skin means that many amperes of current flowing for prolonged periods would usually be required to "cook" organs other than the skin.

An electric arc in air at one atmosphere has a temperature of 2500° to 3000° C and can cause local heat effects other than those due to current passing through skin resistance.[1]

E. Pulsed Current

Repeated brief pulses would seem to offer several decided advantages as a form of delivering electrical energy for incapacitation purposes. At a pulse repetition rate of one per second or faster, pulsed currents should be able to cause as much pain, paralysis and incoordination as continuous current, perhaps even more than continuous direct current. Very brief pulses and a small duty cycle would mean low average power levels, resulting in: (1) reduced burn hazard to the subject; and (2) reduced drain on the power supply system. For example, a one ampere pulse lasting one millisecond (0.25 joule of energy, assuming internal body resistance of 250 ohms) could be repeated at 10 pulses per second with a time-average power of only 2.5 watts, one hundred times less than a continuous current of one ampere. If such pulses passed through major portions of a man's body, they should be completely incapacitating with only minor burn hazard and low drain on the power supply. Figure 1 might be misconstrued to suggest that such a pulsed current is known to be safe as far as the heart is concerned. It must be emphasized that the figure relates to a single

non-repetitive pulse only, and that hazard thresholds for repeated pulses remain to be determined.

Working with data from studies using humans and experimental animals, Zoll and co-workers found that: (1) 3 millisecond pulses of about 100 milliamperes (energy 0.06 joule and less) applied across the chest would trigger a heartbeat; and (2) pulses repeated 8 to 20 times per second for periods on the order of a minute could cause fibrillation in some cases.[5] Thus a one ampere pulse lasting one millisecond (energy 0.25 joule) would be likely to trigger a heartbeat each time the pulse passed through the chest, and a fibrillation hazard could exist in normal hearts subjected to rapid rates of such "external heart pacing" for prolonged periods. From the information presented by Zoll et al, there would appear to be little danger of fibrillation or low cardiac output if the external pacing is carried out at a rate within the normal heartbeat range. Thus a repetition rate of about two pulses per second might prove to be well tolerated for prolonged periods, at least as far as direct cardiovascular hazard is concerned.

Incapacitating pulses passing through the chest at a rate of about two per second are likely to interfere seriously with breathing, and might prevent loud vocalization, along with any other coordinated action. If breathing were stopped by the pulses, the subject could eventually suffocate.

The safety of repeated brief pulses for incapacitation purposes has not been proved by the report dated 25 June 1971. The longest reported test period was four seconds and no evidence is presented with regard to the subjects' cardiac or respiratory status during the test period, the time required for functional recovery after delivery of the last pulse, and the thresholds for "no-let-go" status and skin burns.

F. Overcoming Skin Resistance

As previously noted, human skin and hair often present a major resistive

barrier to delivery of electric current for incapacitation purposes. Methods of overcoming the skin resistance problem may be summarized as follows:

Avoid the skin. Make contact with moist mucosal surfaces such as mouth and rectum.

Use wet skin. Make contact with skin surfaces that are already wet, or deliberately moisten the electrode placement sites.

Use damaged skin. Make wet contact with skin previously or deliberately scratched or abraded, as with an abrasive electrode paste.

Penetrate epidermis with electrodes. Make direct contact with structures beneath the epidermis by means of electrodes in such forms as needles, splinters, burrs and slivers.

Use high voltage. Sufficiently high voltages will force any required current through the skin regardless of high skin resistance. High voltage cannot be considered a simple all-purposed solution to the skin resistance problem because high voltage is likely to cause extremely rapid changes in skin characteristics. A voltage high enough to force an incapacitating current through two high resistance dry skin contacts may well cause small burns that result in a drastic fall in skin resistance; if high voltage is maintained in the face of rapidly declining resistance, an enormous and hazardous current flow develops. Various electrical techniques are available to limit current flow in such cases. Use of high voltages also requires that special precautions be taken to avoid short circuits that bypass the subject's body.

G. Path of Current Flow Through the Body

The complete loop of current flow must be considered in every case of electric shock, and any changes taking place during the shocking process must be borne in mind. The locations of effective current entry and exit from the body are all important with regard to physiologic effect, considering that current has direct effects on only those organs through which it flows.

Two electrodes closely spaced. Current entry and exit points within a few centimeters of each other on the body surface can cause local pain, muscle spasm and burns only. The only significant exception would be electrodes on the front of the chest where part of the current could flow through the heart. Closely spaced electrodes could be used to cause limited incapacitation by pain and, if properly used, could be quite safe.

Two electrodes widely spaced. Widely spaced electrodes on the body surface offer a great variety of possible physiologic consequences, depending on full details of the method used. In all cases, there will be local effects near the electrodes as noted above. Large currents passing between electrodes on opposite sides of the head may have effects similar to electroconvulsive therapy, at the risk of severe scalp burns unless the electrodes provide large areas of good contact; similar effects, along with others, might be expected with current flowing from the top of the head to another electrode at neck level or lower on the body. Current flowing only in one extremity can have direct effects on that extremity only. There are many possibilities for widely spaced electrodes to cause significant current flow through the chest with resultant possibility of interference with cardiac and/or respiratory activity. Figure 2 illustrates the possibilities of placement of contacts that cause a significant proportion of the current to flow through the chest. Electrode pairs offer such a possibility if they: (1) are on opposite sides of the plane AU; (2) are on opposite sides of the plane BC; or (3) are on the front and back of the chest or upper abdomen. Figure 2 shows that the only path from one extremity to another, not threatening chest activities, is from one lower extremity to another.

One electrode and "ground". This situation must be considered as two electrodes, the second electrode being whatever is considered "ground" in contact with both the subject's body and the other part of the essential closed circuit for current. The single electrode problem may be one thing if the subject is standing barefoot in a rice paddy, and entirely different if he is standing in dry shoes on a dry wooden floor. Any change in the subject's body contact with "ground," such as falling onto or away from "ground," can radically alter the current flow situation.

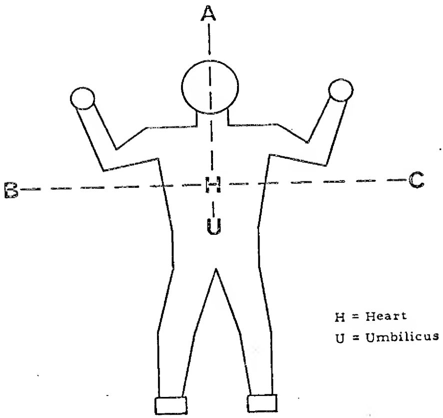


Figure 2. Diagram of Body Area Combinations for Current Flow Through Chest. (See Text)

H. Physiological Conclusions

It is possible to use electrical current as an agent to cause a whole spectrum of human incapacitation from minor distraction through muscle spasm, pain, contortion, minor burns, respiratory arrest and perhaps vocal paralysis, cardiac arrest, unconsciousness with convulsion, severe burns and death.

The approximate degree and duration of incapacitation can, within limits, be predetermined by appropriate selection of current type, amount, duration, and path in the body. In general, electrical techniques tend to be time-limited if safety is a consideration; prolonged use of electric current to maintain incapacitation may present grave hazards to the subject in the form of burns, inadequate heart output or inadequate respiration. On the other hand, a brief "knock-down" incapacitation can be achieved with relative safety by almost any large current flowing for an extremely short period of time (less than a millisecond).

Several techniques can be used to increase the safety factor of current being used to incapacitate for longer than the "knock-down." A current large enough to cause extremely painful paralysis of the extremities presents no danger more serious than burns if it does not pass through the chest. In this respect, optimum safety with severely incapacitating currents could be achieved with the current flowing: (1) from one lower extremity to the other; or (2) from a distal point to a proximal point on the same extremity. Over such paths continuous AC current of more than 25 milliamperes or DC current of more than 80 milliamperes should keep at least one extremity of a man painfully paralyzed for the duration of current flow; currents larger than an ampere could cause severe burns, especially if the current flows continuously for many seconds.

If the current path is through the chest, the use of direct current will virtually obviate the hazard of heart fibrillation although the likelihood of respiratory and cardiac arrest remains with direct currents in the effective range. Cardiac arrest causes unconsciousness within a few seconds and death after several minutes. Complete respiratory arrest usually causes unconsciousness in less than four minutes and death in about ten minutes. Both kinds of arrest would be likely with direct currents larger than 300 milliamperes passing through the chest, so incapacitating direct current would usually have to be kept in the 80 to 300 milliampere range if it is to be used for prolonged periods.

The safety margin for incapacitating levels of alternating current flowing through the chest is narrow for periods as short as a few seconds and there is no margin of safety if the current flows for more than 30 seconds. All such shocks should be considered potentially lethal.

Carefully chosen pulsed currents, perhaps brief surges of one joule or less delivered once or twice per second, may offer effective and relatively safe incapacitation when flowing between any two widely spaced points on the body. Several key questions regarding the safety and effectiveness remain to be answered by direct investigation, but indirect evidence suggests that such pulses would offer the following advantages: (1) no direct threat to a normal heart for any duration of incapacitation; (2) only minor skin burns at worst; and (3) low average current requirement for the power supply. The facts remain to be verified, but such pulses passing from any point on the upper extremities or the upper body to any point below the waist may well be capable of preventing respiration and effective speech in addition to causing complete immobilization by muscle spasm and pain. If this is the case, an operator could be equipped with a system enabling him to: (1) knock a subject down rapidly; (2) keep the subject incapacitated and unable to make an effective outcry for perhaps a minute; (3) turn the pulses off for long enough to allow the subject to take a breath or two; (4) turn the pulses back on until the subject becomes blue or passes out; and (5) repeat steps 3 and 4 for a reasonable length of time. Properly handled, the subject should recover promptly after the pulses have been turned off for several seconds, and have no permanent ill effects aside from probable small-area skin burns.

Electrical currents are not likely to cause the immediate coma and convulsion of electro-convulsive therapy without: (1) severe burns about the head or (2) the use of techniques very similar to those used in ECT.

IV. Other System Factors

A. Major Subsystems

Power Supply. Information presented in the preceding section of this report indicates that: (1) one large non-repetitive pulse lasting less than a second might be appropriate as a "knockdown" technique; and (2) longer incapacitation will require continuous power in the 1 to 250 watt range, quite likely less than 25 watts, depending upon the technique. A large capacitor, previously charged from a primary source, could supply the single brief burst of power. Systems requiring longer duration power could draw upon permanent supply installations, temporary generators, or batteries, as appropriate in terms of power drain and anticipated duration. Power supply reliability should approach 100% in a properly designed system. Power conditioning equipment is needed to make the required changes, such as voltage step-up, temporary storage, current limitation, and modifications with respect to timing. The reliability of power conditioning equipment should also approach 100%.

Controls. Except in special circumstances where some degree of variability or automaticity of current delivery would be desirable, the current control mechanism probably should be a reliable manual on-off switch.

Delivery Conductors. Properly designed conductors should present few problems in systems where the electrical supply components and the electrodes have been prepositioned before the arrival of the subject, who is expected to move himself into appropriate contact with the electrodes. Similarly, short-range conductors, as for a hand-held device, should be quite reliable. A conductor-propulsion combination suitable for swift long-range deployment will require extremely careful design if it is to be

reliable with regard to open-circuit and short-circuit possibilities under a variety of field conditions.

Electrodes. Electrode design and placement will have to allow for all the variables to be presented by the subject and the environment in the field. The subject variables are likely to include location in space, body posture, motion before receiving current, motion and posture after receiving current, clothing, moisture of skin and clothing, nature of surrounding objects, proximity and actions of companions. Subject variability is likely to determine the path of current flow in the body of a subject who moves himself into contact with previously placed electrodes. Again, hand placement should be easy, but swift long-range placement of adequate electrodes will require expert design in order to be reliable under a variety of field conditions. Electrodes are subject to open-circuit and short-circuit failure modes, in addition to dangers or ineffectiveness which might result from inappropriate current pathways through the body.

B. Operator Risk

Standard electrical safety precautions, built into the system, should be adequate for operator safety so long as the operator avoids electrical contact with the electrodes or the subject while current is flowing. The operator could handle the subject if he: (1) turned off the current; or (2) wore insulating gloves of an appropriate thickness.

C. Covertness

Aside from the actions of the subject, electrical current system activity should be inapparent to an observer except for the possible faint snapping noise, smell of ozone or burning and dim light of small high-voltage arcs. As discussed previously, the subject may or may not be able to scream, shout or signal. A severely incapacitated subject is likely to fall down, and might thrash about or jerk under some circumstances.

D. Countermeasures

Only limited countermeasures would be available to protect a subject from a properly designed electrical incapacitation system. In general, countermeasures would fall into the following categories:

Avoidance. Stay away from the electrodes.

Minimize current flow. Current penetration of the body can be effectively reduced by: (1) interposing an insulating layer between the electrode and the body; or (2) providing a low resistance short-circuit path between electrodes so most of the current flow remains outside the body. Insulating footwear could often be a reliable countermeasure to any system using a single electrode with "ground." Insulating gloves might enable a subject to remove electrodes delivering currents above the "no-let-go" threshold if initial electrode placement does not provide a completely incapacitating path of current flow through the body. Protective clothing could have a low resistance (short-circuiting) outer layer and a high resistance (insulating) inner layer.

Interrupt current flow. Once a truly incapacitating current flow has been established in the subject's body, deliberate interruption of the current could be accomplished only by the operator or a third party coming to the aid of the subject.

V. Equipment State-of-the-Art

The system is the only electrical incapacitation unit for which the authors of this report have detailed information. The concept may be summarized as a self-contained, hand-carried, battery-powered unit designed to project one or two insulated delivery wires at high velocity to a subject who may be at ranges up to 100 meters; delivery wire(s) may terminate at electrode(s) that may be bare wire, net, dart, barb, burr, adhesive or some other form; current is passed through the subject in brief 0.1 to 3 joule pulses at about 30,000 volts repeated 2 to 20 times per second. Data are presented from tests involving a small number of experimental animals and human volunteers. During these tests, incapacitation periods were limited to four seconds or less.

In view of the information presented in this report, the concept appears basically sound provided that a reliable wire delivery and electrode emplacement system can be proved satisfactory under field conditions. From the physiological standpoint, safer and more rapid incapacitation might have been achieved with larger energy pulses repeated more slowly than the ten per second indicated in most of the tests. Available test information is not conclusive with regard to: (1) incidence of skin burns; (2) respiratory and vocal status during shocks; (3) whether or not personnel knew that they were "pacing" the hearts of the subjects; (4) effects of prolonged exposure to the pulses; and (5) results when electrodes are projected to the subjects rather than carefully taped in position.

Incomplete descriptions of other systems for incapacitation by electric current are also available. One is a patent application for a pistol that would produce "artificial epilepsy" by firing a small projectile with two trailing wires, the projectile to be equipped with two forward-facing needle electrodes

to penetrate the skin of the subject. The only way for such a device to cause a true generalized convulsion would be for the needles to penetrate the subject's brain! Closely spaced electrodes can cause only local direct effects. Elsewhere on the body, such a device could cause annoyance, pain and possibly burns before the subject removed the projectile.

Streams of conductive fluid, such as impure water, have been suggested as alternatives to conventional metallic conducting wires and electrodes. Such suggestions have merit so long as practical considerations of range, time, and open-circuit and short-circuit problems are kept in mind.

VI. Recommendations

1. Arrange to have necessary experimental work done in order to establish appropriate thresholds of effectiveness and safety for pulsed currents. The physiologic effects and hazards of selected pulsed currents could be substantially proved by appropriate observations with a small series of experimental animals. Common domestic animals, such as pigs, sheep, and calves that weigh about 70 kilograms, provide good models for adult men as far as electrical effects are concerned. Audio-cinematographic, electrocardiographic and pneumographic recording should be carried out with emphasis on the time of onset of apparently incapacitating muscular contraction, cardiac and respiratory status during incapacity, the recovery phase, and examination of the sites of electrode placement. Time-to-incapacity, ability to make an outcry and time-to-recover would have to be investigated with a small series of unanesthetized animals; other phases could use animals breathing spontaneously under light anesthesia. Judicious increases in duration of the incapacitation period and the energy and frequency of the pulses should yield useful approximations of the desired thresholds for humans. Other studies on the operation of electrodes and power supply could be conducted at the same time. Once burn thresholds have been established, the "no-let-go" threshold could be documented with a brief study using a palm-to-shoulder current path in human volunteers.

2. Encourage development of systems to fit specific needs. Any single electrical system is unlikely to prove optimum for all situations in which incapacitation is desired, especially with regard to making two appropriate electrical contacts with the subject's body and maintaining them if prolonged incapacitation is required.

3. High voltage is likely to prove the most practical way to overcome the skin resistance problem in many situations; if high voltage is used, the

likelihood of small-area third degree skin burns must be accepted. High voltage systems will need special provisions to avoid: (1) delivering excessive current to the subject after a fall in skin resistance; (2) shocking the operator; or (3) short circuits that could destroy effectiveness of the system before or after the start of incapacitation.

4. A short-range (arm's length) electrical current incapacitation device could be operational in a few months. The device could be a "pain dispenser" carried in the hand, and could consist of a modified surgical towel clip with battery-powered electronics to provide painful shocks.

5. Proposed systems should be examined critically, especially with regard to the resistance problem and the location of the entry and exit points for current flowing through the body. Unless a system has a reliable method of preventing current flow through the subject's chest, it should be assumed that current will flow through the chest in some cases. A single electrode with "ground" system is likely to be dependable in special situations only.

6. All systems intended to maintain incapacitation for more than a few seconds should deliver currents well above the "no-let-go" threshold in order to insure that the subject will not be able to break contact manually.

7. Operators should be aware that a subject's gun is likely to be fired if the subject has a finger on the trigger at the moment electrical incapacitation starts.

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